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HYDRAULIC CHARACTERISTICS OF A
RAPID INFILTRATION LAND TREATMENT SYSTEM

By

Brian A. Borgstadt

Brian A. Borgstadt
A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Engineering, South Dakota
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1978

HYDRAULIC CHARACTERISTICS OF A RAPID INFILTRATION LAND TREATMENT SYSTEM

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Date

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Brian

INTRODUCTION

Land application methods are becoming increasingly important for disposal of wastewater. The application of sewage effluent to the land is not a new method of waste disposal, but it is likely to play an important role in future water pollution control planning. Rapid infiltration land application [previously referred to as infiltration percolation by EPA reports (1)] is gaining recognition as an effective method of wastewater renovation.

Rapid infiltration is a controlled procedure in which sewage effluent is applied to the soil by spreading in basins or by sprinkling (2). Pollutants are removed from the wastewater by natural, physical, chemical, and biological processes as they travel through the soil matrix. The objectives of a rapid infiltration system may include (a) recharge of the ground water table, (b) natural treatment of wastewater followed by recovery through pumped withdrawal or underdrains, and (c) natural treatment by movement through the soil and recharging a surface watercourse (2).

Infiltration basins have produced excellent treatment results at several locations including Phoenix, Arizona; Lake George, New York; and Fort Devens, Massachusetts (1).

Land treatment of wastewater has been the subject of several Master of Science theses at South Dakota State University. Tiltrum (3) and Sherman (4) performed lysimeter studies on stabilization pond effluents at Brookings and Madison, respectively. In 1974, the City

of Brookings decided to help the Civil Engineering Department at South Dakota State University in the construction of a pilot unit employing the rapid infiltration process in the vicinity of the Brookings stabilization pond to further the study.

A pilot unit was constructed during the summer of 1974. It consisted of three basins, with an underdrain for each basin, and application piping to inundate each basin with stabilization pond effluent. In the following years, the pilot unit was operated as the subject of further studies with funding provided by a research grant from the Environmental Protection Agency. During 1975, Alsaker (5) studied the ability of the pilot unit to provide treatment of wastewater sufficient to comply with future discharge standards; Miller (6) evaluated winter operating constraints; and Voogt (7) investigated infiltration rates and ground water hydraulics of the unit. In 1976, the study was continued with DeMers (8) investigating compliance with discharge standards; Larson (9) further defining infiltration rates and ground water hydraulics; and Dickinson (10) describing the fate of nitrogen as the wastewater passed through the system.

In 1977 several additions were made to the pilot units and a different flooding procedure was undertaken. The author assisted in making these changes and continued the studies concerned with the infiltration rates and ground water hydraulics portions of the research.

The objectives of this portion of the overall study were to:

1. Describe and evaluate improvements and additions that were made to the rapid infiltration pilot unit during 1977,
2. Evaluate the infiltration capacities of the basins with respect to the application procedure and to compare these rates with the results of prior studies,
3. Compare the groundwater table response with respect to the change in operation, and
4. Determine the effect of precipitation and water levels of Six Mile Creek on the ground water table in the area of the pilot unit.

BROOKINGS PILOT UNIT STUDIES

The studies of Tiltrum (3) and Sherman (4) indicated extremely low infiltration rates for the disturbed soil that had been compacted into their pilot lysimeters. In an effort to determine if land treatment could be made practical for Brookings, it was decided to construct an infiltration-percolation pilot unit near the Brookings stabilization ponds.

During the summer of 1974 the pilot unit was constructed. The soil in the area was similar to that found in the area of a proposed full scale system. The site was near the stabilization ponds to minimize piping and consisted of nearly level ground to minimize construction grading (Figure 1). The soil in the area had been classified as Lamoure silty clay loam (7).

The units consisted of three basins of approximately 7500 square feet (698 m^2) with 3 foot (0.9 m) dikes (Figure 2). Each basin was underlain with 4-inch (100-mm) perforated drain tile at a depth of about 30 inches (760 mm). A perforated drain tile was also installed around the perimeter to minimize interception of native ground water (7). A sampling box was constructed, complete with a buried pipe that was installed to allow free discharge to Six Mile Creek. A piping arrangement was constructed to carry stabilization pond effluent to the units by gravity flow.

The basins were designated north, middle and south. The north and south basins were scarified, leveled and rototilled to a depth of

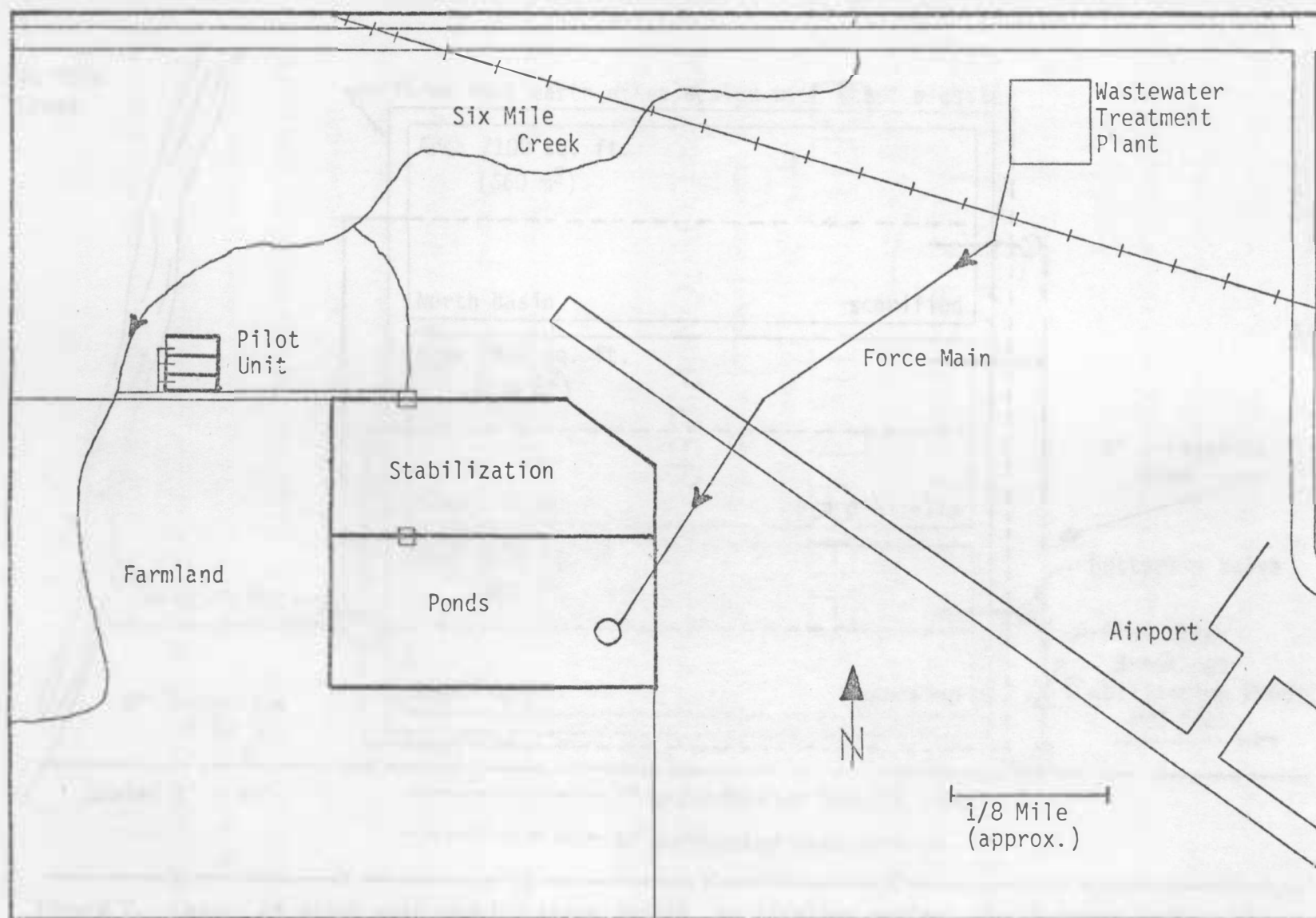


Figure 1. Overview of area showing wastewater treatment plant, stabilization ponds, pilot unit, and Six Mile Creek (7).

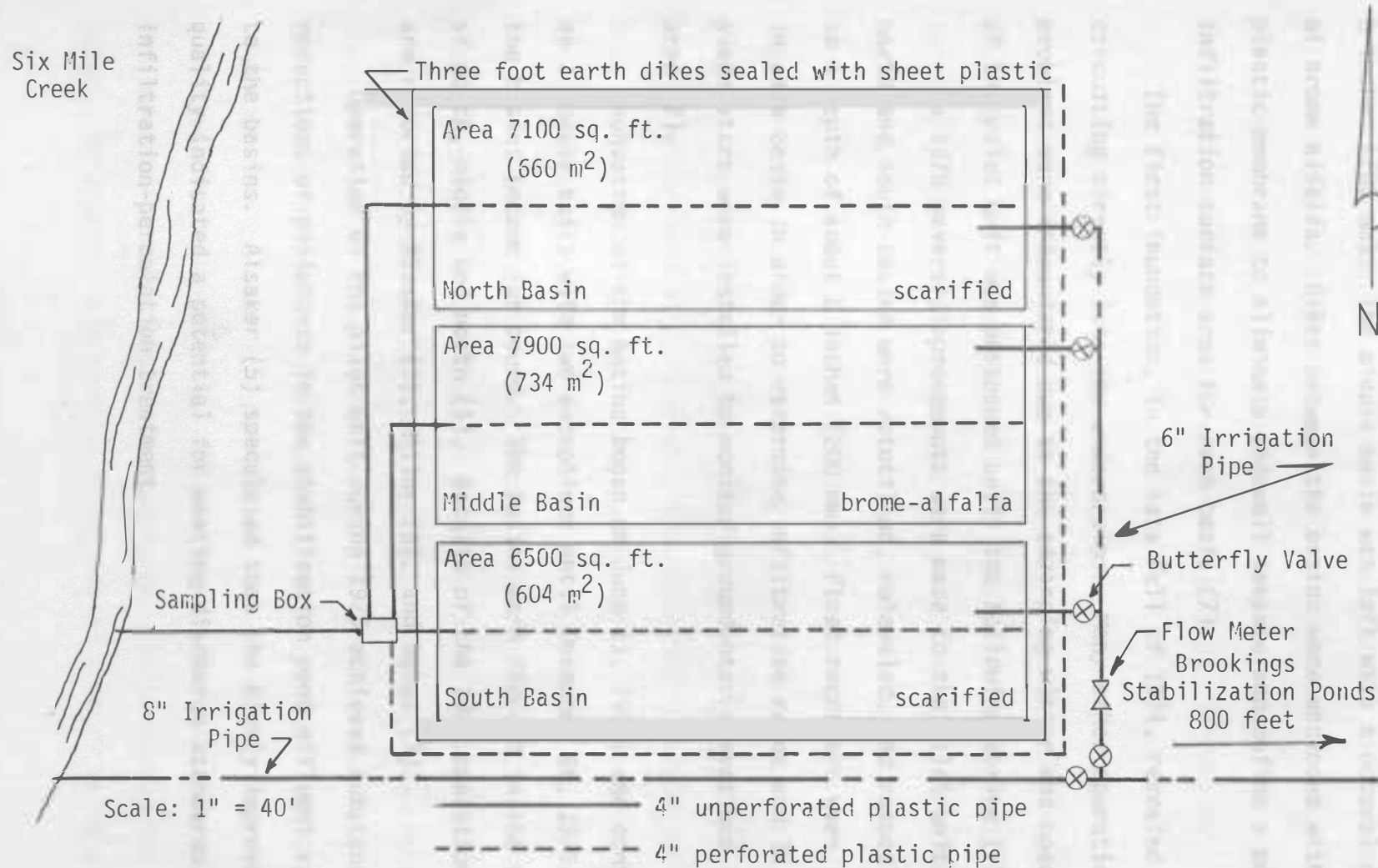


Figure 2. Layout of pilot unit showing three basins, application system, and drainage system to Six Mile Creek, 1976 (5).

8 inches (200 mm). The middle basin was left with a natural cover of brome alfalfa. Dikes between the basins were enclosed with a plastic membrane to eliminate sidewall seepage and define a measurable infiltration surface area for each basin (7).

The first inundation, in the late fall of 1974, revealed short circuiting directly into the underdrains. Many other operational problems were encountered due to the advancing winter and operation of the pilot unit was postponed until the following spring (7).

In 1975 several improvements were made to the pilot unit. The north and south basins were rototilled, releveled, and rototilled again to a depth of about 8 inches (200 mm). Float recorders were installed in each basin in order to determine infiltration rates and 38 piezometers were installed to monitor groundwater elevations in the area (7).

Inundation of the basins began on June 11, 1975, and continued on a weekly basis with two exceptions until December 16, 1975, when the basins became ice bound. The basins were flooded in the sequence of south, middle and north (5). Results of the 1975 operation period are reported by Alsaker (5), Miller (6), and Voogt (7).

Operation of the pilot unit during 1975 achieved substantial reductions of pollutants in the stabilization pond effluent applied to the basins. Alsaker (5) speculated that the highly improved quality indicated a potential for meeting discharge standards by infiltration-percolation treatment.

Miller's study of winter operating constraints (6) observed a serious problem with ice accumulations and manual operation of the unit. As winter approached, lower infiltration capacities and a trend toward poorer quality in the effluent developed, indicating a need for storage in such a system.

Infiltration rates were found to be noticeably influenced by antecedent moisture and not substantially affected by influent suspended solids concentration (5, 7). Voogt also reported that the groundwater mound that formed as a result of inundating the basins had completely receded before another inundation period began (7).

In the spring of 1976 several changes were made to the pilot unit to correct the short circuiting that was experienced the previous season. The soil over the drain tiles was compacted and the resulting depression was filled with clay. The clay was then compacted and the rest of the north and south basins were disturbed to a depth of 18 inches (460 mm) with a frost ripper and were then rototilled.

The six piezometers that Voogt (7) had installed across each basin were removed and placed on the dikes between the basins and at selected locations around the basins because it was believed that they had aided in short circuiting in 1975 (9). Three wells were installed at points around the pilot unit in April of 1976 to provide additional information for groundwater monitoring.

Operation of the system during 1976 proved more effective than in 1975 for the removal of pollutants from applied wastewater. DeMers (8) reported treatment efficiencies of from 79 to 92 percent

for BOD_5 , 85 to 94 percent for suspended solids, 80 to 91 percent for ammonia nitrogen and 89 to 98 percent for fecal coliforms. The basins did not, however, consistently meet ammonia nitrogen and fecal coliform standards.

The higher loading rate and scarified surface of the south basin were shown statistically by Dickinson (10) to improve ammonia nitrogen and organic nitrogen removals although other variables such as soil types were believed to have had a greater effect. The rapid infiltration system was successful in removing ammonia nitrogen but relatively large quantities of nitrate nitrogen were produced in the effluent.

Larson (9) observed that climatic factors that influenced evapotranspiration had a major effect on infiltration rates. Rainfall was not a large factor, however, due to a thick plant cover on the basins and an uncommonly dry summer. The ground water mound that resulted from flooding the basins, as described by Larson (9), was found to be quite uniform and centered beneath the middle basin. The ground water mound rose to within three (80 mm) to six inches (150 mm) of the basin surface and receded rapidly. Ground water contour maps were drawn and the shape of the contours before floodings was attributed to location of the drains and possibly to a variability of soil types in the area.

More detailed results obtained at the pilot units during the 1976 operating season are presented by DeMers (8), Larson (9), and Dickinson (10).

IMPROVEMENTS AND ADDITIONS AT THE PILOT UNIT DURING 1977

In an effort to improve treatment and to better understand the ground water hydraulics of the area, several improvements were made at the rapid infiltration pilot unit during 1977. The improvements included additional, deeper drains for the basins, a new sampling box, the installation of a stage recorder on nearby Six Mile Creek, and the installation of an additional well.

DeMers (8) and Dickinson (10) believed that improved treatment might result from lowering of the underdrains of the system. Also, Larson (9) hypothesized that the installation of more drains would allow the soil to drain faster and reduce the height of the ground water mound, thus allowing the application of more wastewater.

New drain tiles were installed in each basin at a depth of approximately 50 inches (1.3 m). The 4-inch (100-mm) perforated plastic drain tiles were buried longitudinally under each basin near the natural ground water level. The trenches for the drains were made with a 6-inch (150-mm) commercial trencher when possible. The high ground water level led to frequent collapsing of the trench requiring the use of a backhoe to excavate a suitable trench. The drains were covered with sand and the remainder of the backfill consisted of material that had been excavated from the trenches. An attempt was made to compact the backfill with a hand compactor in one foot (0.3 m) lifts followed by compaction of the trench with the wheel of the

backhoe. Before releveling of the basins, a commercial compactor was used to compact the soil of each trench.

A large wooden sampling box was constructed near the pilot units to allow for the collection of samples from each underdrain. The shallow underdrains from the previous system were kept intact and were extended to reach the new sample box, thus making it possible to obtain samples from two different soil depths. Two pumps were installed in the sample box to pump the water to a line discharging to Six Mile Creek.

The gravity feed system that had been used during prior seasons (7) was arranged to flood the basins from the west end and a by-pass line was again assembled to conduct flow to Six Mile Creek while the basins were not being inundated. Figure 3 is a graphical representation of the rapid infiltration pilot unit as it was operated in 1977.

An automatic stage recorder was constructed immediately west of the infiltration basins to record the water surface level of Six Mile Creek during the operating season. A Stevens Type A35 Recorder with a negator spring motor drive was placed on a dock extending from the bank into the creek. An 8-inch (200-mm) section of plastic pipe, open at both ends, served as a stilling basin for the float assembly. In this manner, a continuous record of the free water surface elevation of Six Mile Creek was obtained. The chart traveled 2.4 inches (61 mm) per day and a 1-foot (0.3-m) change in water level was recorded by a 1-inch (25-mm) deflection of the stylus of the recorder.

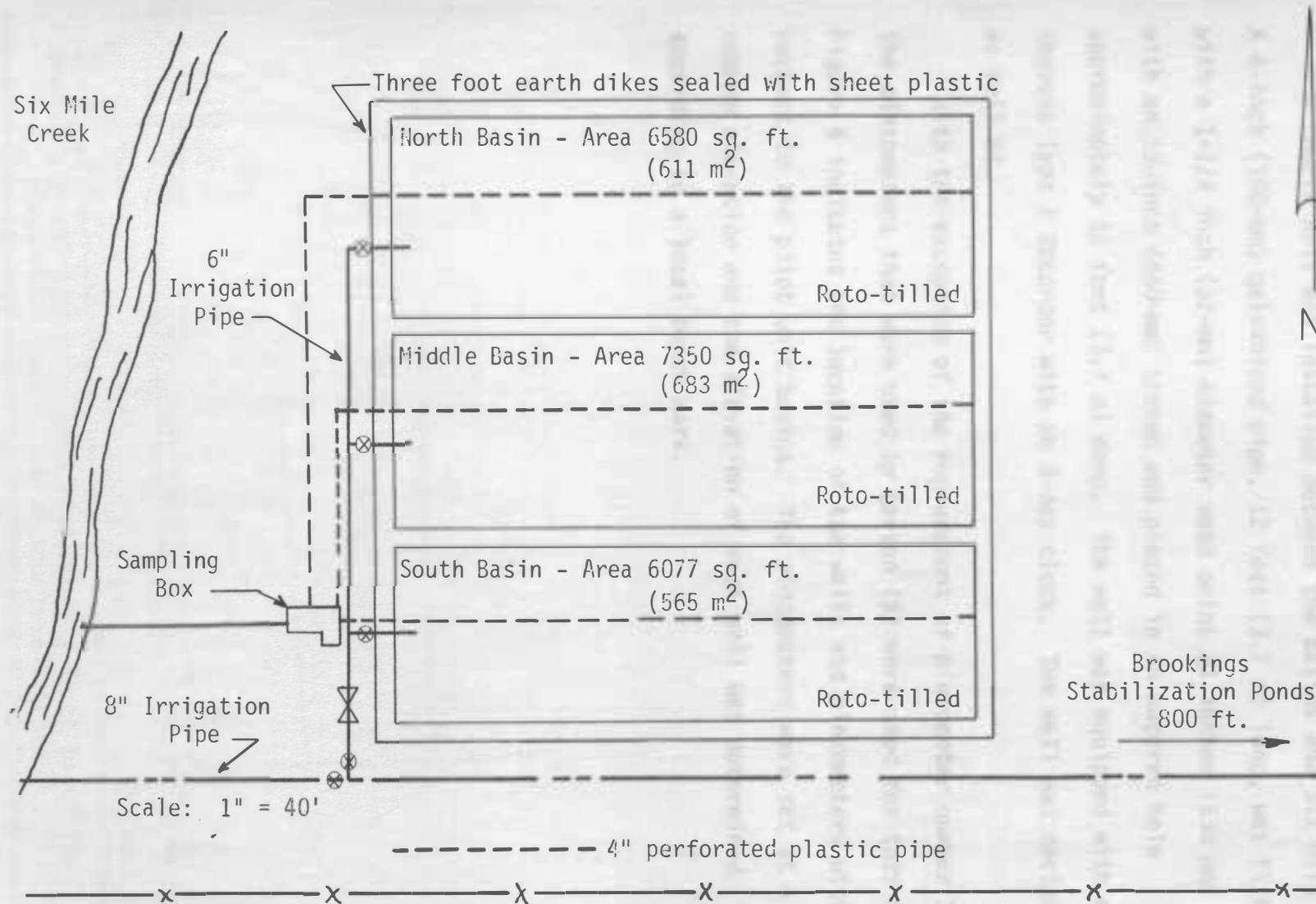
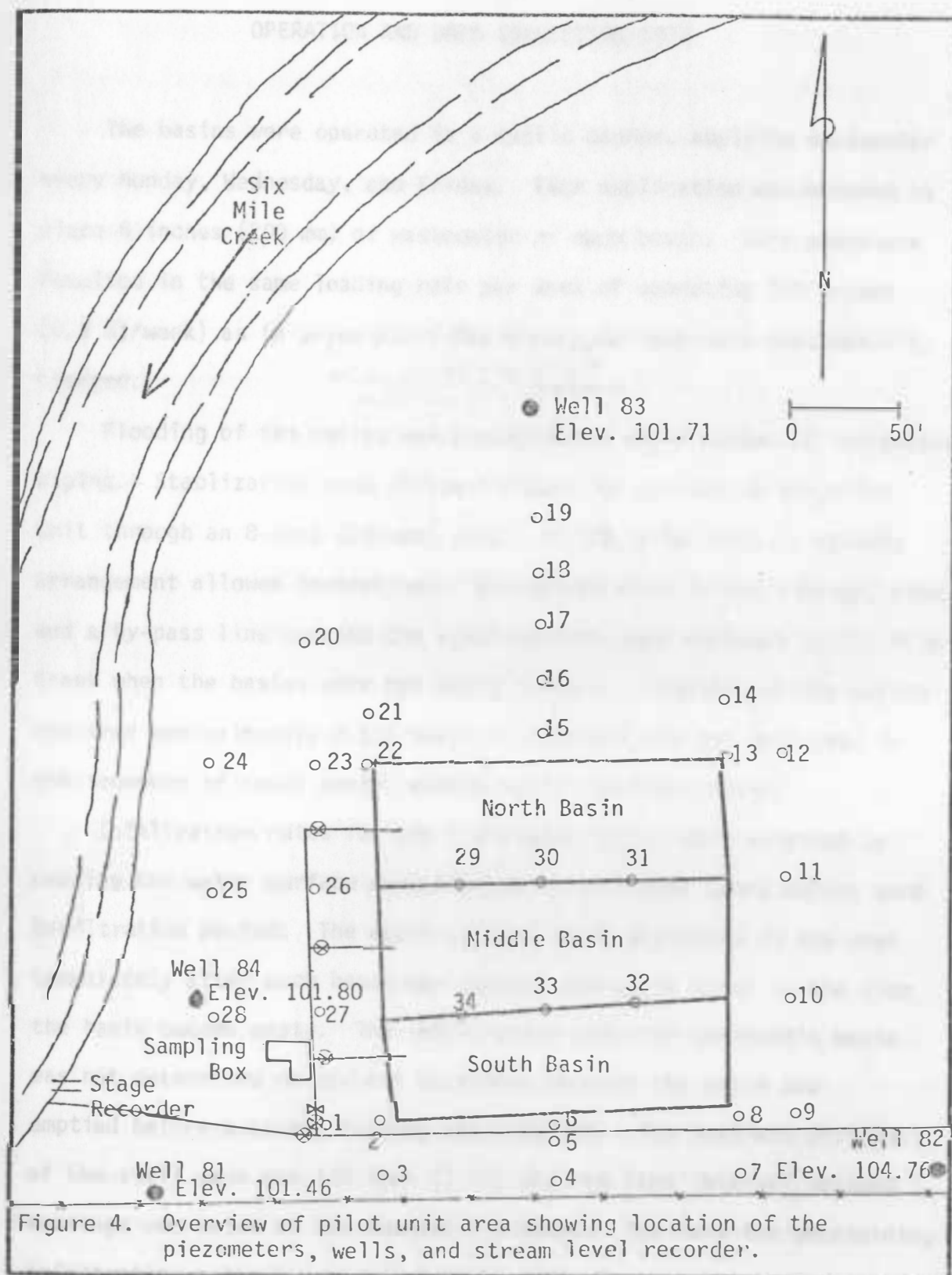


Figure 3. Layout of the pilot unit showing three basins, application system, and added drainage system to Six Mile Creek as occurred in 1977.

A fourth well was installed between the basins and Six Mile Creek. A 4-inch (100-mm) galvanized pipe, 12 feet (3.7 m) long, was fitted with a 1-1/4 inch (32-mm) diameter sand point 21 inches (530 mm) long with an 18-inch (460-mm) screen and placed in an augered hole approximately 12 feet (3.7 m) deep. The well was equipped with a Stevens Type F Recorder with an 8-day clock. The well was designated as Well 84.

With the exception of the replacement of piezometer number 33, the piezometers that were used by Larson (9) were used for this study. Figure 4 indicates the location of the wells and piezometers with respect to the pilot unit basins. The piezometers were set at a common elevation and the elevation of each well was determined according to a local bench mark.





OPERATION AND DATA COLLECTION 1977

The basins were operated in a cyclic manner, applying wastewater every Monday, Wednesday, and Friday. Each application was metered to place 8 inches (200 mm) of wastewater on each basin. This procedure resulted in the same loading rate per week of operation (24 inches (0.6 m)/week) as in prior years but drying periods were substantially changed.

*OK for middle + south basins
North had 18" in 1975*

Flooding of the basins was accomplished via a system of irrigation piping. Stabilization pond effluent flowed by gravity to the pilot unit through an 8-inch (200-mm) pipe. At the pilot unit, a valving arrangement allowed inundation of the basins with 6-inch (150-mm) pipe and a by-pass line carried the stabilization pond effluent to Six Mile Creek when the basins were not being flooded. Flooding of the basins required approximately 3-1/2 hours to complete and was performed in the sequence of south basin, middle basin and north basin.

Infiltration rates for the individual basins were obtained by reading the water surface elevation on a staff gage twice during each infiltration period. The water surface level was noted on the gage immediately after each basin was flooded and again prior to the time the basin became empty. The infiltration rate for the middle basin was not determined on several occasions because the basin had emptied before a second reading was obtained. The smallest division of the staff gage was 1/8-inch (3-mm) and the time interval between readings was noted to the nearest 5 minutes. The data for determining infiltration rates may be found in Appendix A.

Samples of stabilization pond effluent were collected from the influent to each basin only on Wednesdays and composited in equal volumes for analysis. Samples of the effluent from each basin were collected every 4 hours from the tile drain for Wednesday floodings. The samples were composited for each drain and analyzed in the Civil Engineering Department laboratories. The tests performed on the samples included: biochemical oxygen demand (BOD); suspended solids (SS); specific conductance, pH, ammonia-nitrogen, nitrate-nitrogen, kjeldahl nitrogen, and phosphorus. These analytical determinations were made by other members of the research team.

Temperature, evaporation, and precipitation data for the operation period were obtained from official climatological data of the Brookings weather station (11). Weather data can be found in Appendix B.

The piezometers were read using an electric meter that responded when the wire leads made contact with a water surface. The 34 piezometers were read immediately prior to each flooding cycle and at 4-hour intervals on Wednesdays for a total of eight times per week. On Wednesday, the piezometers were read at 7:30 a.m., 3:30 p.m., 5:30 p.m., 9:30 p.m., and 11:30 p.m. This reading schedule was established from several readings taken during the first flooding cycle. The schedule provided data to establish the rate of formation of the ground water mound and the rate of recovery of the ground water table. For convenience reasons, the samples from the drain tiles were collected at approximately the same times as the piezometers were read. The piezometers were cleaned and releveled approximately every 4 weeks to prevent clogging.

Ground water level data for the wells were obtained from stage recorders fitted to each well. Recorders on wells 81 and 82 were equipped with 30-day clocks and wells 83 and 84 were fitted with 8-day clocks. The free water surface of Six Mile Creek was monitored using a Stevens A35 automatic stage recorder with a calibrated chart which ran all season. Ground water elevation data at the well locations and the data concerning the water surface elevation of Six Mile Creek may be found in Appendix C.

EVALUATION OF INFILTRATION DATA

The infiltration rate of the soil is defined as the rate at which water enters soil from the surface. The infiltration rate of a saturated soil profile is equal to the effective saturated permeability of the soil profile (1). Infiltration data for the pilot unit were collected from August 31 to October 12, 1977. The average infiltration rates for the basins are presented in Table 1 along with the data obtained by Voogt (7) in 1975 and Larson (9) in 1976.

The average infiltration rate for each basin has been decreased in each consecutive season of operation. Several factors including changes in pilot unit operation that might be responsible for the decrease in infiltration rates have been investigated.

Effect of Pilot Unit Changes

An effort was made in 1976 to halt the short circuiting phenomena of the previous season. Compaction of the soil above the drains was assumed to have reduced short circuiting based on the improved treatment reported by DeMers (8). If short circuiting was eliminated, the result would not only be improved treatment but also lower infiltration rates.

In 1977, operation of the pilot unit was aimed at reducing infiltration rates to improve treatment further. Lower infiltration rates would promote longer contact with the soil and thus enhance treatment. Lower infiltration rates were induced by a flooding

Table 1
Average Infiltration Rates During Percolation
Rapid Infiltration Pilot Unit
1975, 1976, and 1977

Basin	Infiltration Rate (in./hr.)*			
	Maximum	Minimum	Median	Mean
North				
1975	1.10	0.56	0.78	0.79
1976	0.80	0.27	0.63	0.57
1977	0.25	0.08	0.16	0.16
Middle				
1975	1.36	1.07	1.23	1.22
1976	1.68	0.93	1.38	1.34
1977	0.89	0.51	0.74	0.74
South				
1975	0.94	0.54	0.70	0.69
1976	0.65	0.23	0.47	0.45
1977	0.18	0.07	0.15	0.14

*1 in./hr. = 25.4 mm/h

schedule that inundated the basins more frequently. Wastewater was applied essentially every two days resulting in virtually no drying period. Infiltration rates are higher when the soil profile is relatively dry because water is entering large pores and cracks but when moisture levels are high, clay particles swell reducing the infiltration rate (1, 12). In 1977, moisture levels in the soil remained high as a result of the frequency of flooding the basins. In this manner, infiltration rates were substantially reduced.

Factors Affecting Infiltration Capacities

The infiltration capacity of a soil is the maximum rate at which the soil is capable of absorbing water. Infiltration capacities of moist soils are extremely variable (12). The factors affecting the infiltration capacity of a soil include soil moisture, compaction due to rain, in-wash of fine material, compaction by man and animals, the macrostructure of soil, vegetative cover, entrapped air, and temperature (12, 13). A combination of these factors may be responsible for the following observations concerning infiltration rates.

The average infiltration rate for the middle basin increased in 1976 compared to 1975 and then substantially decreased in 1977 (Table 1). During the first year of operation, the surface of the middle basin consisted of natural brome-alfalfa. Operation of the pilot unit in 1976 yielded extensive growth of several species

determined by natural selection and in 1977 all plant growth on the basin was rototilled into the surface.

The presence of a dense cover of vegetation tends to promote rapid infiltration (12). The vegetative cover of the basin was more extensive in 1976 than in 1975 and thus higher infiltration rates were recorded. The vegetative cover provided protection from compaction by rain and also provided a layer of decaying organic matter which promotes the activity of burrowing insects and animals (12). Evapotranspiration rates were found by Larson (9) to substantially affect infiltration rates in 1976. Removal of the vegetative cover in 1977, combined with the more frequent application schedule, reduced the infiltration capacity of the middle basin to its lowest level in the past 3 years.

For each year of operation, the infiltration rate for the north basin has been found to be statistically different from the infiltration rate of the south basin. Voogt (7) believed that the difference might be caused by a longer contact time of the wastewater on the south basin since the south basin received 24 inches (0.6 m) of wastewater and the north basin received only 18 inches (0.46 m) of wastewater. Infiltration rates are expected to decrease with longer contact times for an inundation period (1, 13); thus, the average infiltration rate for the south basin would be expected to be lower than the average infiltration rate for the north basin.

Identical loading rates were used the following year for Larson's study. Larson (9) attributed the difference in infiltration rates between the north and south basins to a difference in soil types beneath the basins. The pilot unit is located in the flood plain of Six Mile Creek and consequently the soil beneath the basins is likely to be very diversified.

An analysis of variance test was used to investigate the difference in infiltration rates of the basins for 1977. The results of this statistical test are presented in Appendix D. The north basin was found to exhibit a significantly different infiltration rate than the south basin at the 95 percent confidence level. Since the loading rates of both basins were identical, it appears that any difference in infiltration rates can be attributed to the difference in soil types beneath the basins. Since the loading rates were identical and the only variable of any consequence was soil type, it appears that any difference in infiltration rates could be explained by this variable.

The infiltration rates for the three basins, as recorded in the 1977 study period, are shown graphically in Figure 5. The infiltration rates for the middle basin were substantially higher than those for the north and south basins. These consistently higher rates might be attributed to the condition of the surfaces of the basins. Although each basin surface had been rototilled at the beginning of the operating season, the middle basin had never been scarified and, therefore, consisted of an upper layer of soil that could have contained a greater amount of dead vegetable matter than the other

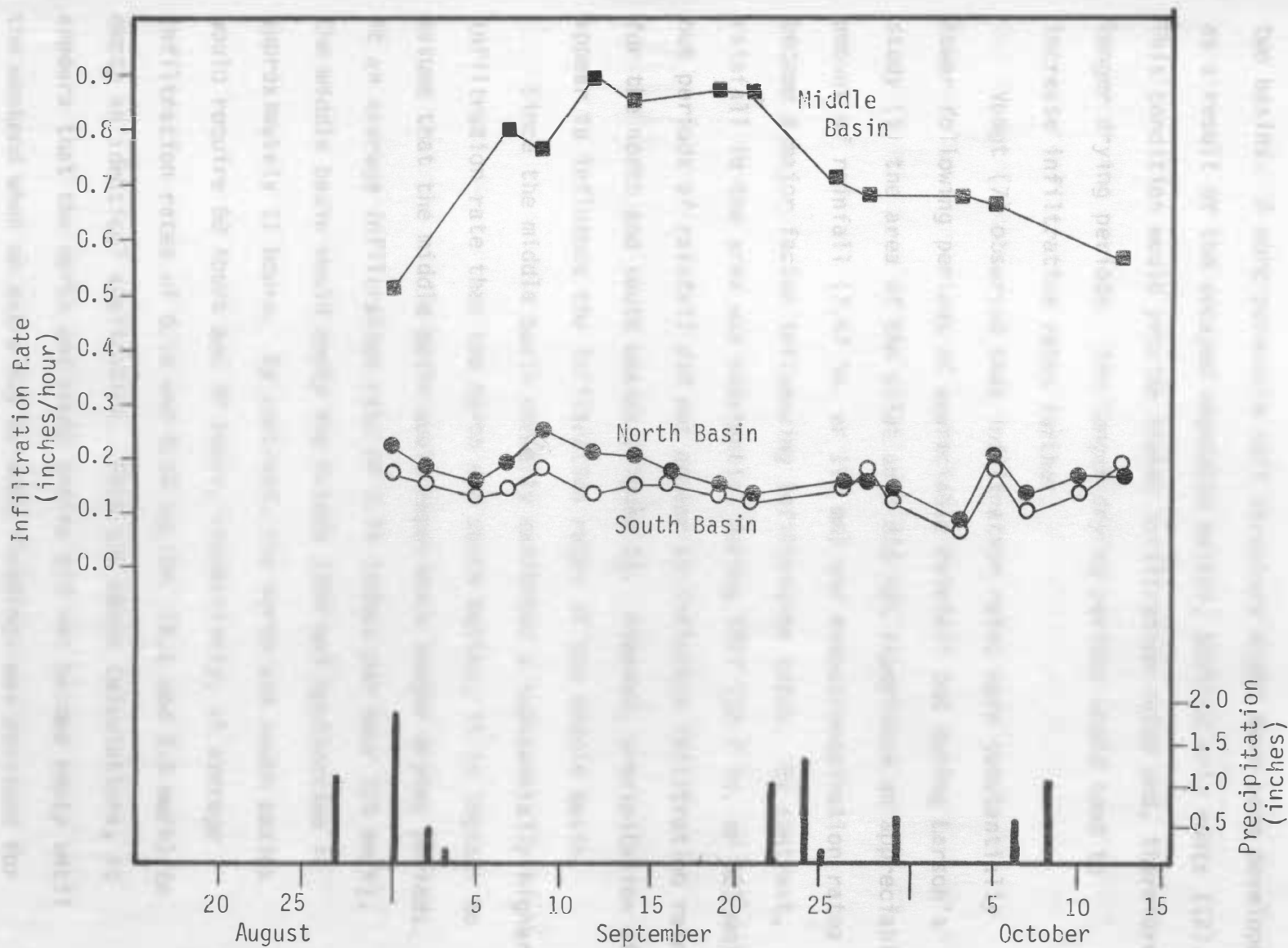


Figure 5. Infiltration rates for individual basins and precipitation, 1977.

two basins. A more permeable soil structure might have been developed as a result of the decayed vegetable matter, particularly roots (12). This condition would provide higher infiltration rates and, therefore, longer drying periods. The longer drying periods would tend to increase infiltration rates further.

Voogt (7) observed that infiltration rates were substantially lower following periods of appreciable rainfall but during Larson's study (9) the area of the pilot unit did not experience an appreciable amount of rainfall (7.67 in. or 195 mm) and evapotranspiration rates became a major factor influencing infiltration rates. By contrast, rainfall in the area was substantial during 1977 (12.7 in. or 323 mm) but periods of rainfall did not appear to influence infiltration rates for the north and south basins (Figure 5). However, precipitation did appear to influence the infiltration rates of the middle basin.

Since the middle basin normally exhibited a substantially higher infiltration rate than the north and south basins, it is logical to assume that the middle basin would experience longer drying periods. At an average infiltration rate of 0.74 inches per hour (19 mm/h), the middle basin would empty the 8-inch (200 mm) application in approximately 11 hours. By contrast, the north and south basins would require 50 hours and 57 hours, respectively, at average infiltration rates of 0.16 and 0.14 in./hr. (4.1 and 3.6 mm/h) to empty an identical application. From the above calculations, it appears that the north and south basins did not become empty until the weekend when an extra day between floodings was provided for

drying. Observations recorded in the field notes during the flooding season confirm that beginning with the flooding of August 24 and thereafter a substantial amount of water frequently remained on the north and south basins prior to the addition of more wastewater. The substantial difference in levels of antecedent moisture in the basin surface at the time of rainfall could explain the decrease in infiltration capacity experienced by the middle basin in September and October without substantially affecting the north and south basins.

Soil Clogging Analysis

A review of the literature concerning land treatment reveals a concern for clogging of the soil system (14). The most important cause of the loss of infiltrative capacity of the soil is biological and organic clogging (13). Surface clogging is a result of the deposition of suspended solids in pore spaces and the reduction of pore space due to bacteria growing on entrapped solids (13). The average level of suspended solids for the 1977 operating season was 27.3 mg/l and the maximum concentration was 49.0 mg/l (15). These levels of suspended solids may be expected to cause problems with surface clogging (14).

The loss of infiltrative capacity can be the result of continuous inundation which enhances the growth of anaerobic organisms on organic matter in the soil resulting in clogging of the soil system (13). Anaerobic activity which produces clogging includes overgrowth of organic slimes, precipitation of ferrous

sulfide, accumulations of polysaccharides, and changes in soil characteristics due to any interaction with organics (13). An examination of the data regarding nitrogen removals (16) indicates that a denitrification process occurred in the soil profile thus anaerobic conditions were present in the system. However, aerobic conditions at the soil surface may have prevented a trend toward clogging of the soil surface. Resting of the soil by draining and reestablishment of an aerobic system will lead to a recovery of the soil infiltrative capacity (13).

Equilibrium Infiltration Rate

A soil system under continuous prolonged inundation will exhibit an infiltration rate that approaches an equilibrium level. The time required for a system to approach its equilibrium infiltration rate depends on organic loading and characteristics of the soil. Various soils and various water qualities promote a long-term equilibrium infiltration rate that is quite low and tends to be constant regardless of the initial infiltration rate (13).

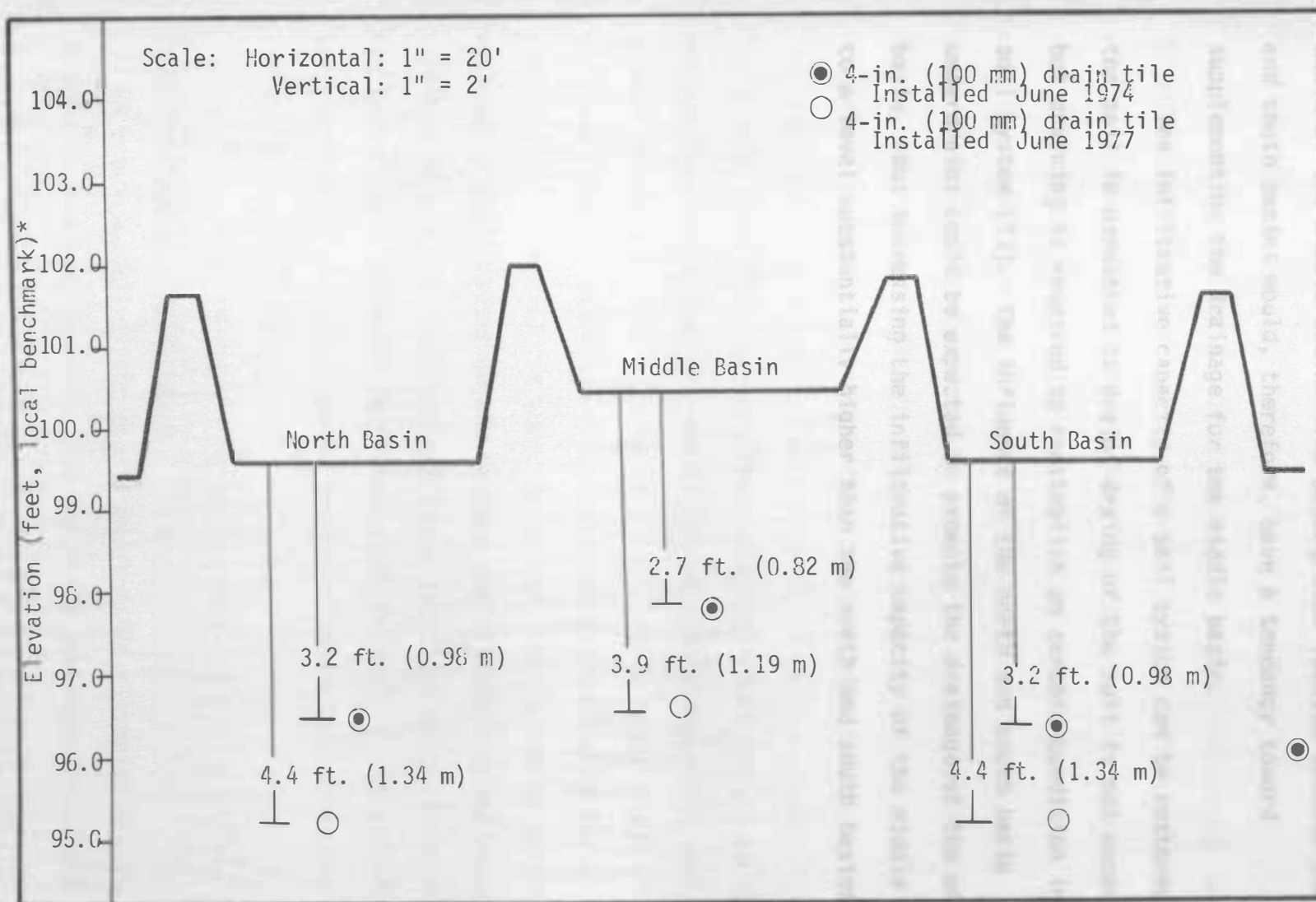
During Voogt's study on continuous inundation (7), a minimum equilibrium infiltration rate of approximately 0.5 in./hr. (12.7 mm/h) was recorded for the middle basin and approximately 0.7 in./hr. (17.8 mm/h) was recorded for the north and south basins. However, the pilot unit suffered from short-circuiting problems and infiltration rates began to increase when a greater hydraulic head

of water began forming on the basins near the end of the special one-week study.

During the 1977 study, infiltration rates were not available for the early part of the season; however, Figure 5 shows a tendency toward a steady state or equilibrium infiltration rate for the north and south basins. The equilibrium value for the soils in these pilot units appears to be approximately 0.15 in./hr. (3.8 mm/h) or 3.6 inches (91 mm) per day; a value that is slightly higher than the infiltration rate predicted by Tiltrum from his lysimeter study (3). The equilibrium infiltration rates obtained by the compacted soil in the lysimeters were 0.09 in./hr. (2.3 mm/h) and 0.04 in./hr. (1.0 mm/h) with a hydraulic head of approximately 3 inches (76 mm). The steady-state (equilibrium) infiltration rate becomes extremely important as the basis for the designing of hydraulic loading rates for rapid infiltration systems (1).

Effect of Physical Characteristics of Pilot Unit

When the pilot unit was constructed in 1974, the north and south basins were scarified and the overburden was used to form dikes around the basins. The middle basin was never scarified; consequently, the surface of the middle basin is approximately 1.0 foot (0.3 m) higher in elevation than the other two basins as shown in Figure 6. As a result of this difference in surface elevation, the old and new underdrains of the north and south basins are approximately 0.7 foot (0.2 m) lower in elevation, respectively, than



*1 ft. = 0.305 m

Figure 6. Profile view of rapid infiltration pilot basins showing relative depth of drains below basin surfaces, 1977.

those of the middle basin. The underdrains located beneath the north and south basins would, therefore, have a tendency toward supplementing the drainage for the middle basin.

The infiltrative capacity of a soil system can be restored if the soil is permitted to drain; drying of the soil is not necessary but draining is required to reestablish an aerobic condition in the soil system (13). The influence of the north and south basin underdrains could be expected to promote the drainage of the middle basin, thus increasing the infiltrative capacity of the middle basin to a level substantially higher than the north and south basins.

GROUND WATER RESPONSE

A mounding effect of the ground water occurs when large amounts of wastewater are applied to the land in a basin. The ultimate height of the ground water mound is affected by infiltration rates, hydraulic conductivity of the soil and temperature of the water. An underdrainage system is sometimes required when the groundwater is near the surface to ensure rapid drainage of the soil profile during drying. The ground water mound under natural conditions should not be allowed to rise to more than four feet from the surface, unless the mound tends to recede rapidly after infiltration stops (14). The ground water flow system below a disposal field should be analyzed to insure that the aquifer can transmit the water fast enough to avoid an excessive buildup of a ground water mound (14).

The rapid infiltration pilot unit was equipped with basin underdrains to control the mounding effect anticipated to result from wastewater applications to the basins, and piezometers had been inserted in the soil in the immediate area of the unit to monitor the ground water response to flooding of the basins. To illustrate the response of the ground water, several figures are presented in the following sections.

Response During Flooding Cycle

A cross section of the ground water table elevation may be observed along a north-south line utilizing piezometer readings as

shown in Figure 7. (See Figure 4 for exact locations of the piezometers.) The dashed lines represent dikes of the basins. Three profiles are shown in Figure 7: a profile before flooding of the basins, a profile of the ground water table 8 hours after flooding began, and a profile 16 hours after flooding began. The profiles were drawn using a 4-week average of values obtained from actual piezometer readings from September 21 to October 12, 1977.

Similar profiles were drawn by Larson (9) for the 1976 operating season. The profile representing the water table before flooding showed a dishing out effect in 1976, indicating a definite drainage of ground water below a natural level. By contrast, the same profile in 1977 shows no dishing out effect. Actually, there may not have been a complete recession of the ground water mound between floodings. The difference was probably brought about by the shortening of the interval between floodings. The time between applications was too short to allow complete drainage of the soil. The more frequent wastewater applications and lower infiltration rates lengthened the period in which water would enter the upper soil layers in 1977.

In Figure 7, the profile representing the ground water table 8 hours after flooding approximates the maximum level that was observed during the cycle. In 1976, the maximum level was observed approximately 15 hours after flooding began. Again, the change in infiltration rate is probably a major factor as well as the amount of wastewater placed on the basin in a single application; 8 inches (203 mm) per application in 1977 and 24 inches (0.6 m) per

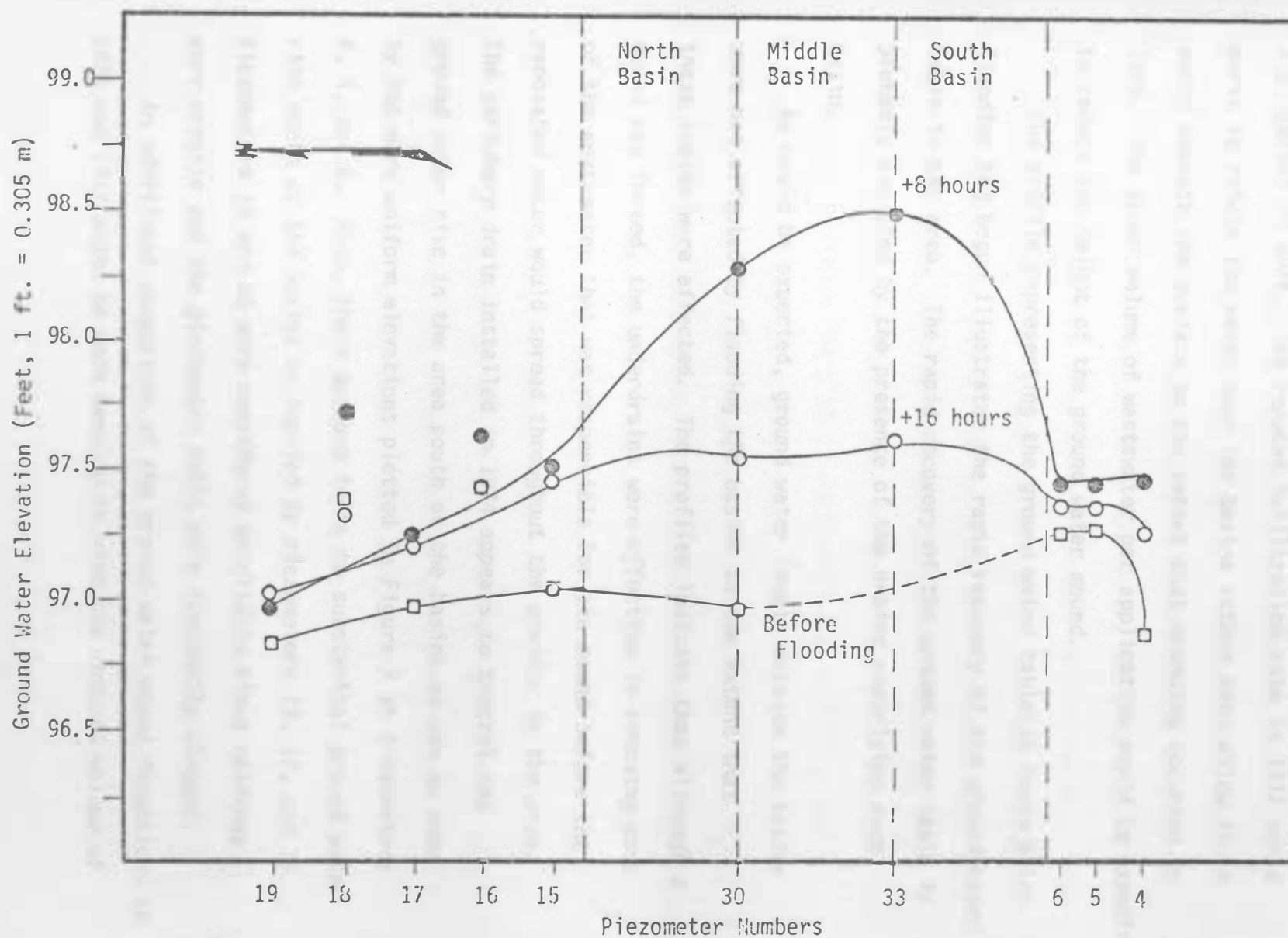


Figure 7. Profile of ground water table during the flooding cycle; 4-week average, 1977.

application in 1976. The reduced infiltration rate in 1977 would serve to retain the water over the basins rather than allow it to mound beneath the surface to the extent that mounding occurred in 1976. The lower volume of wastewater per application would be expected to reduce the height of the ground water mound.

The profile representing the ground water table 16 hours after flooding had begun illustrates the rapid recovery of the ground water table in the area. The rapid recovery of the ground water table is probably assisted by the presence of the drains underlying each basin.

As would be expected, ground water levels outside the basins were not affected by flooding the basins to the extent that those inside were affected. The profiles indicate that although a mound was formed, the underdrains were effective in removing most of the wastewater that was responsible for the mound before the renovated water would spread throughout the aquifer in the area. The periphery drain installed in 1974 appears to control the ground water rise in the area south of the basins as can be seen by the more uniform elevations plotted in Figure 7 at piezometers 4, 5, and 6. Also, there appears to be no substantial ground water rise north of the basins as implied by piezometers 15, 17, and 19. Piezometers 16 and 18 were considered unreliable since readings were erratic and the piezometer tubes were frequently clogged.

An additional comparison of the ground water mound formations in 1976 and 1977 might be made keeping in mind the reduced volume of

wastewater applied and the lower infiltration rates achieved in 1977. Ground water elevations, as measured at piezometer 30, are plotted in Figure 8 for representative flooding cycles as occurred in 1976 and 1977. Piezometer 30 is located on the dike between the north and middle basin midway between the ends of the basins. This piezometer was chosen for comparison because it provided consistently reliable data of the ground water response beneath the pilot unit itself. Both plots represent changes at the same location, at approximately the same time of year and during a period when rainfall was not substantial. The plot of data collected in 1977 contains one complete flooding cycle (Wednesday, August 17) up to the time immediately before another inundation is to take place. The plot representing data obtained in 1976 includes the flooding cycle but only one of the six days between flooding cycles (September 1 - 3).

Figure 8 indicates that in 1977 the rise of the ground water mound was only about 50 percent of the rise in 1976, the maximum rise of the mound was realized in much less time and recovery was very rapid. However, the ground water table did not recover completely before another flooding cycle began.

Figure 8 also shows the relative positions of the ground water table before the flooding cycle began. During 1977, the ground water level was approximately 1-ft. (0.3 m) higher before flooding was started. The ground water table may have been maintained at a higher level due to two major factors: more frequent inundation of the basins and the greater rainfall in 1977. The higher mound

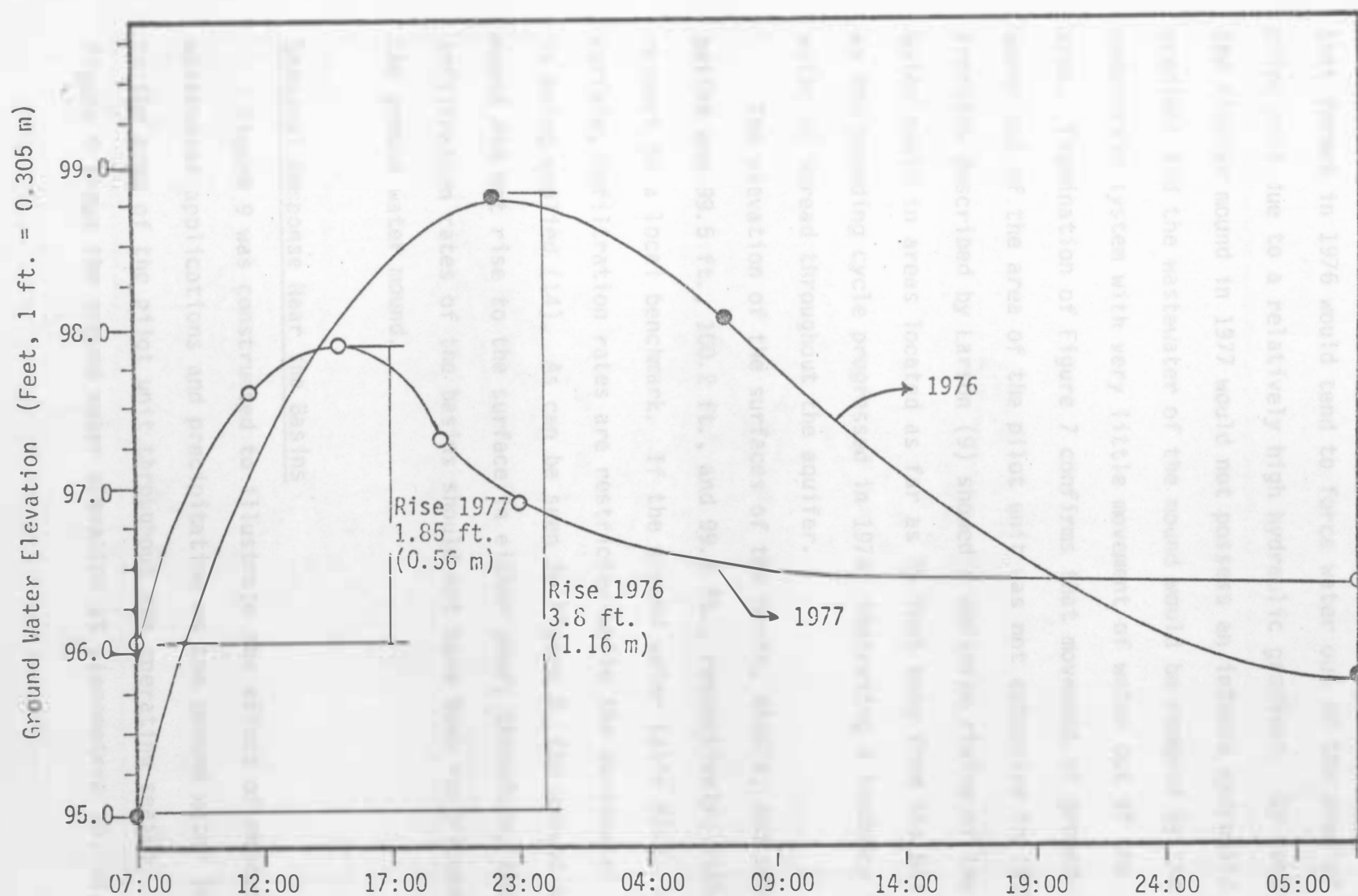


Figure 8. Ground water elevations during flooding cycle at piezometer 30, 1976 and 1977.

that formed in 1976 would tend to force water out of the area of the pilot unit due to a relatively high hydraulic gradient. By contrast, the flatter mound in 1977 would not possess an intense hydraulic gradient and the wastewater of the mound would be removed by the underdrain system with very little movement of water out of the area. Examination of Figure 7 confirms that movement of ground water out of the area of the pilot unit was not extensive in 1977. Profiles described by Larson (9) showed a definite rising of the water table in areas located as far as 75 feet away from the basins as the mounding cycle progressed in 1976; indicating a tendency for water to spread throughout the aquifer.

The elevation of the surfaces of the north, middle, and south basins are 99.5 ft., 100.2 ft., and 99.5 ft., respectively, with respect to a local benchmark. If the ground water table rises to the surface, infiltration rates are restricted while the wastewater is being applied (14). As can be seen in Figure 8, the ground water mound did not rise to the surface in either year; therefore, the infiltration rates of the basins should not have been restricted by the ground water mound.

Seasonal Response Near the Basins

Figure 9 was constructed to illustrate the effect of repeated wastewater applications and precipitation on the ground water level in the area of the pilot unit throughout the operating season.

Figure 9 shows the ground water elevation at piezometers 10, 30, and

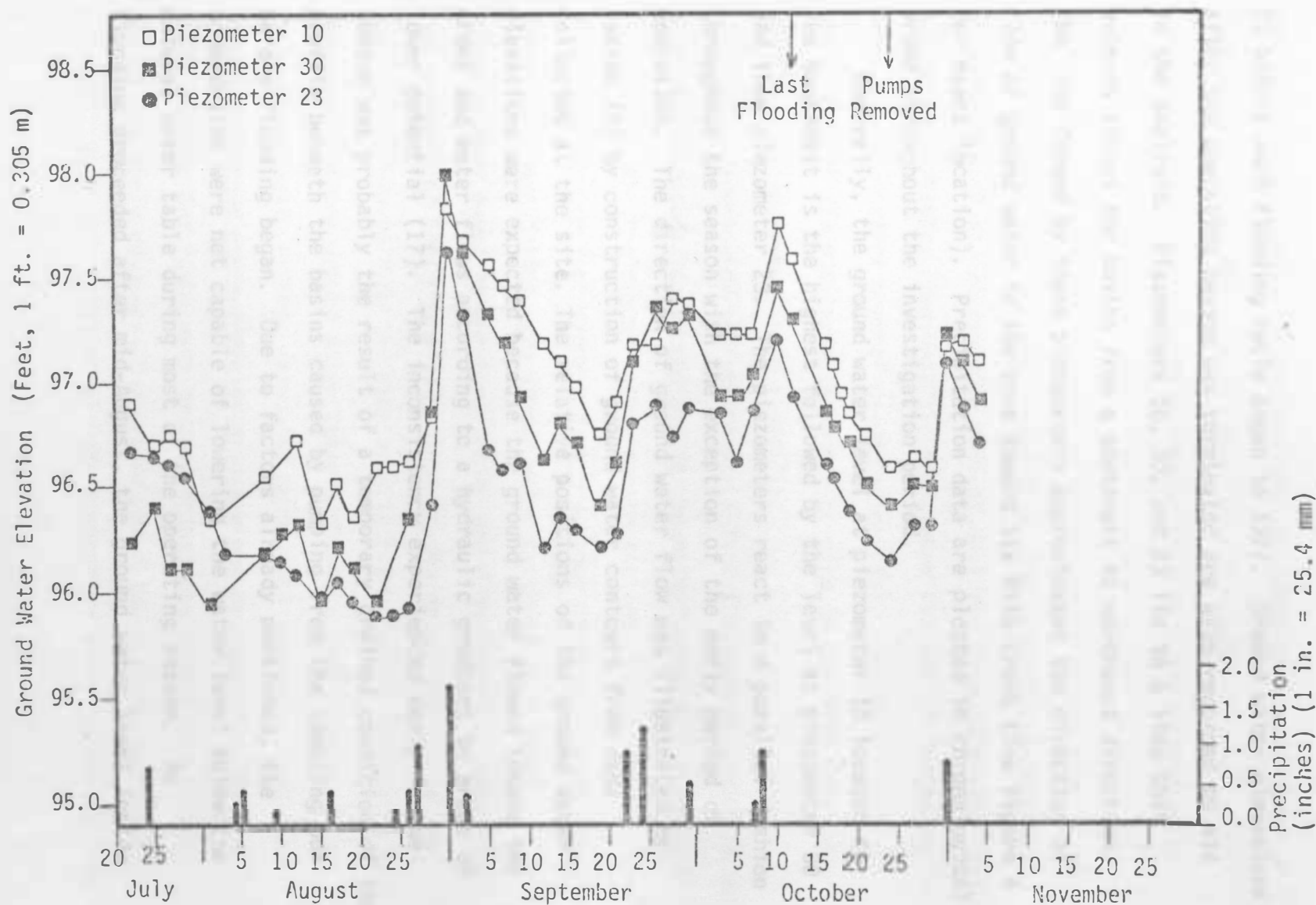


Figure 9. Ground water elevation at piezometers 10, 30, 23 before floodings and precipitation, 1977. (See Figure 4 for exact locations.)

23 before each flooding cycle began in 1977. Ground water elevations after the operating season was terminated are also recorded to aid in the analysis. Piezometers 10, 30, and 23 lie in a line that extends across the basins from a southeast to northwest direction. The line formed by these piezometers approximates the direction of flow of ground water in the area toward Six Mile Creek (See Figure 4 for exact location). Precipitation data are plotted in chronological order throughout the investigation period.

Generally, the ground water level at piezometer 10 located to the southeast is the highest followed by the level at piezometer 30 and then piezometer 23. The piezometers react in a parallel fashion throughout the season with the exception of the early period of operation. The direction of ground water flow was illustrated by Larson (9) by construction of ground water contours from data collected at the site. The relative positions of the ground water elevations were expected because the ground water flowed toward the creek and water flows according to a hydraulic gradient to areas of lower potential (17). The inconsistency experienced early in the season was probably the result of a temporary drained condition of the profile beneath the basins caused by pumping from the sampling box before flooding began. Due to factors already mentioned, the underdrains were not capable of lowering the water level below the natural water table during most of the operating season. As flooding proceeded after mid-August, the ground water level inside

the basin at piezometer 30 was not drained below the water level of piezometer 23 that was located closer to the creek.

Rainfall in the area had a similar effect on the ground water level at all three piezometers. The 1.8-inch (46 mm) rainfall of August 31, 1977, raised the level of ground water in the area at all the piezometers very sharply. Similarly, the rainfalls experienced on September 22 and 24 caused a more gradual and less extensive rise in the water table. The rainfall of October 7-8 was of low intensity and produced another gradual ground water rise. However, this rainfall did not cause the water to rise in Six Mile Creek as did the previously-mentioned rainfalls.

After flooding of the basins was halted (October 12), the ground water table receded quite rapidly as shown in Figure 9. During the flooding season the ground water beneath the basins had risen approximately one foot representing a storage of water. When flooding operations were halted, the ground water returned to a level approximately equal to the level experienced during early operation. The lowering of the ground water table appeared to cease when the pumps were removed from the sample collection station indicating that the return of the ground water table might have been brought about by the underdrain system. When the pumps were removed, the drains became submerged and artificial drainage was halted. A rainstorm shortly after the pumps were removed raised the ground water level again. In early November, the ground water table began to recede naturally at a very substantial rate suggesting the possibility that

nearby Six Mile Creek may have an important influence on the drainage of the area. Monitoring of the ground water level was abandoned after November 4 because of freezing weather.

Influence of Six Mile Creek

The free water surface of Six Mile Creek was monitored continuously during the period of study in 1977. The elevation of the free water surface was also recorded prior to each flooding and the values obtained are presented in Figure 10 along with ground water elevations determined at the same time at well 81 and well 82. Data for wells 83 and 84 closely paralleled the data for well 81 and it was therefore deemed unnecessary to include the data for well 83 and well 84 in Figure 10. Ground water elevation data for wells 83 and 84 may be found in Appendix C, however. Precipitation data were recorded on Figure 10 to demonstrate the effect of rainfall in the area.

The ground water level at well 82 was consistently higher than well 81 with one brief exception. Well 82 is located in an area where the soil surface is substantially higher in elevation than well 81. The higher surface elevation in turn usually leads to a higher water table. The one exception, at the end of August, when well 81 had a higher ground water elevation than well 82, was probably caused by the rapid rise in Six Mile Creek after a substantial rainfall.

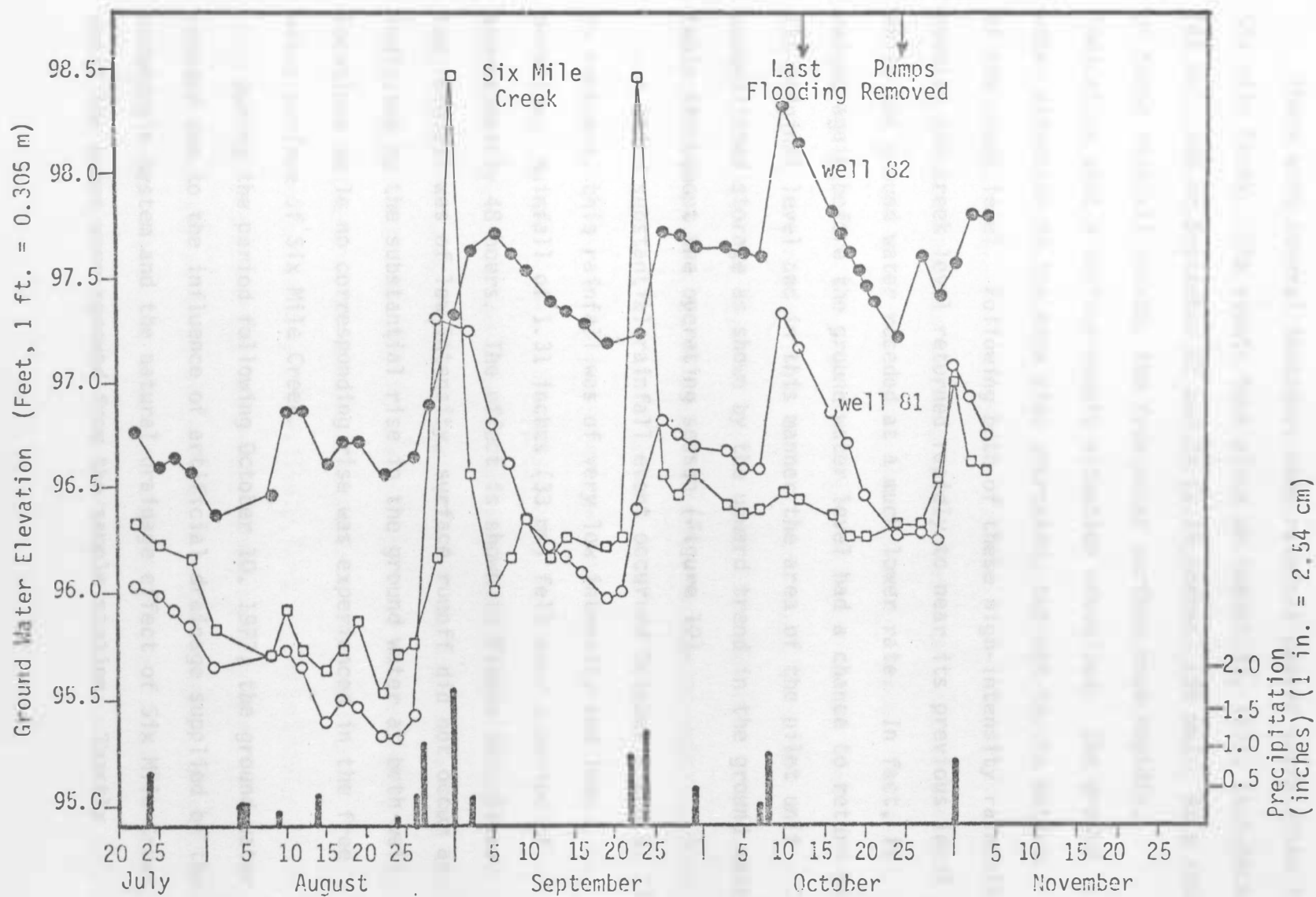


Figure 10. Free water surface elevation of Six Mile Creek, groundwater elevation at well 81 and well 82, and precipitation, 1977. (See Figure 4 for exact locations.)

There were several instances when rainfall caused sharp rises in Six Mile Creek. The events took place on August 31, 1977, (1.8 inches) (46 mm), and on September 22 and 24 (2.19 inches) (56 mm). As a result of these rainfall events, the free water surface rose rapidly, indicating that a surface runoff situation prevailed. The ground water elevation in the area also increased, but not to the extent of the creek level. Following both of these high-intensity rainfall events, the creek level returned rapidly to near its previous level while the ground water receded at a much lower rate. In fact, it rained again before the ground water level had a chance to return to its original level and in this manner the area of the pilot unit accomplished storage as shown by the upward trend in the ground water table throughout the operating season (Figure 10).

A third substantial rainfall event occurred October 7 and 8, 1977. By contrast, this rainfall was of very low intensity and long duration. Rainfall of 1.31 inches (33 mm) fell over a period of approximately 48 hours. The effect is shown in Figure 10. Since the rainfall was of low intensity, surface runoff did not occur as indicated by the substantial rise in the ground water at both well locations while no corresponding rise was experienced in the free water surface of Six Mile Creek.

During the period following October 10, 1977, the ground water receded due to the influence of artificial drainage supplied by the underdrain system and the natural drainage effect of Six Mile Creek until the pumps were removed from the sample station. Shortly

thereafter, the water level in well 82 started rising. A rainfall event then caused another rise in the Creek level and the ground water in the area. The water levels began to recede again at well 81 but this time only natural drainage due to Six Mile Creek was available and well 82 was not influenced. The ground water study was terminated on November 4, 1977, due to a freezing rain that was an indication of the winter conditions that were to follow.

Six Mile Creek was shown to undergo both an influent and an effluent stream condition during the operating season. The creek was probably contributing water to the ground water in the area (an influent condition) until the rainfall of August 27-August 31. The rainfall caused the level of ground water and the creek to rise rapidly. The creek receded rapidly while the ground water receded more slowly as the creek began drawing water from the aquifer (an effluent condition). In mid-September, the creek was again in an influent condition until the rainfalls of late September again raised the water levels as had occurred in late August. The creek again assumed an effluent condition and continued to draw water from the ground water until October 20 when it appeared as though the ground water elevation and the creek water surface had stabilized. Flooding of the basins had ceased, a relatively long period without rainfall had passed, and the pumps had been removed when a rainfall event again raised the water levels and Six Mile Creek became an effluent stream. Thus, it can be seen that the water level in Six Mile Creek greatly influences the ground water levels in the area of the pilot

basin. The creek also served to remove renovated water not pumped from the drains during the times when the creek was in an effluent condition.

SUMMARY

Several studies concerning land treatment of wastewater have been conducted at South Dakota State University in recent years. A lysimeter study conducted in 1973 using soil from the Brookings area and stabilization pond effluent exhibited extremely low infiltration rates. In an attempt to determine if land treatment was feasible for the Brookings area, a rapid infiltration pilot unit was constructed in the vicinity of the Brookings stabilization ponds. The pilot unit was operated with limited success during 1975 and 1976. In an effort to improve treatment, deeper drain tiles were installed in the basins and a more frequent flooding schedule was undertaken in 1977.

The basins were inundated essentially every other day resulting in virtually no drying period between floodings. To provide information of the hydraulic characteristics of the pilot unit, infiltration rates were recorded for each basin, ground water levels in the area of the pilot unit were monitored, and the free water surface level of Six Mile Creek was continuously recorded.

The infiltration data that were recorded in 1977 indicated that infiltration rates of two of the basins were comparable to the rates observed in the lysimeter study of 1973. An equilibrium infiltration rate was observed for these two basins. However, the infiltration rate of the third basin did not reach an equilibrium condition and appeared to be influenced by substantial rainfall in the area.

Ground water data collected at piezometers were utilized to evaluate the ground water mound that was formed in the area of the pilot unit. The formation and recession of the mound could be compared to the characteristics of the mound that formed in prior years of operation of the pilot unit. The creek near the pilot unit was shown to be an influence on the drainage of the area since it tended to stabilize ground water levels in the area.

CONCLUSIONS

Operation of the rapid infiltration pilot unit in 1977 was successful in substantially reducing infiltration rates and improving the treatment of the wastewater applied. The installation of a stage recorder on nearby Six Mile Creek made it possible to determine the relationship between the ground water in the area and the drainage effects of the creek. An evaluation of the data collected from the operation of the pilot unit has led to the following conclusions.

Infiltration rates were substantially reduced with respect to prior years of operation as a result of physical alteration of the pilot unit. Short circuiting was arrested and a more frequent flooding schedule was undertaken. These factors results in higher levels of antecedent moisture in the basin surfaces. The higher moisture content of the soil probably led to swelling, which, in turn, would thus restrict the infiltration rates. Biological clogging was not found to be a factor during this study.

The middle basin was observed to exhibit substantially higher infiltration rates than either the north or south basins. This higher rate was attributed to the condition of the basin surfaces as well as the physical characteristics of the pilot unit. It is believed that the underdrains for the north and south basins tend to supplement drainage of the middle basin, thus indirectly increasing the infiltrative capacity of the middle basin.

The infiltration rates for the north basin were found to be significantly different from those of the south basin. Based on the 1977 data which were collected under conditions whereby each basin was operated as identically as possible, the difference in the infiltration rates of the north and south basin has been attributed to different soil types beneath the basins. The infiltration rates for the north and south basin approached an equilibrium infiltration rate of 0.15 inches per hour (3.8 mm/h), a value comparable to the infiltration rates measured during Tiltrum's lysimeter study.

Due to the lack of vegetation on the basins, evapotranspiration rates were not a major consideration for infiltration rates in this study. However, rainfall in substantial amounts was found to influence infiltration rates of only the middle basin. The middle basin is believed to be affected because of its relatively low moisture content under normal conditions induced by its higher infiltration rate.

The height of the ground water mound in 1977 was shown to be substantially lower when compared to the mound that occurred from operation of the unit in previous seasons. This change was the result of lower application volumes per flooding cycle and reduced infiltration rates in 1977. The ultimate height of the ground water mound was realized in approximately 8 hours and recovery of the ground water table was rapid.

Substantial amounts of rainfall had caused the ground water elevation throughout the area of the pilot unit to rise. The

underdrains and pumping system were demonstrated to be effective in preventing the ground water from rising to the basin surface -- a condition which might result in a restriction of the infiltration rates of the basins.

Six Mile Creek was shown to be influenced by rainfall in a manner dependent on rainfall intensity. The creek was shown to be influential in controlling the level of the ground water in the area of the pilot unit. When rainfall events greater than 1 in. (25.4 mm) took place, the ground water table rose and the creek became a factor in the drainage of the area. When the ground water table had receded, the creek, fed by stabilization pond effluent, began supplying water to the aquifer; thus, the creek operates as a stabilizing influence. Six Mile Creek was shown to flow as both an influent and effluent stream during the operation of the pilot unit. The phase in which the stream operated was dependent to a large extent on the precipitation in the area.

RECOMMENDATIONS

In view of the data and conclusions from the operation of the rapid infiltration pilot unit during 1977, the following recommendations are offered for consideration:

1. The basins of the pilot unit should be tilled prior to each operating season to prevent clogging of the soil surface.
2. Longer drying periods should be permitted in the cooler fall months to extend the length of the operating season. An extended drying period of one or two weeks for either the north or south basins might be attempted to evaluate the influence on infiltration rate and treatment.
3. Piezometers should be placed on the dikes surrounding the pilot-unit basins to better evaluate the ground water mound.
4. The renovated water that is pumped from the sampling station should be metered in order to determine the degree of recovery of water versus applied wastewater.

LITERATURE CITED

1. Process Design Manual For Land Treatment of Municipal Wastewater, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and U.S. Department of Agriculture Publication, (October 1977).
2. Land Treatment of Municipal Wastewater Effluents - Design Factors 1, Environmental Protection Agency Technology Transfer Seminar Publication, (January 1976).
3. Tiltrum, Charles Alan, Soil Infiltration for Tertiary Treatment of Stabilization Pond Effluent, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1974).
4. Sherman, William B., The Infiltration of a Lagoon Effluent for Final Waste Treatment, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1975).
5. Alsaker, Dayton H., High-Rate Infiltration-Percolation Treatment of Wastewater to Satisfy Effluent Requirements, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1976).
6. Miller, Eugene A., Winter Operating Constraints of a High-Rate Infiltration-Percolation Treatment System for Wastewater, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1977).
7. Voogt, Donald Jay, Infiltration and Hydraulic Characteristics of a High Rate Land Application Wastewater System, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1976).
8. DeMers, Larry D., Meeting Wastewater Discharge Standards By Use of High-Rate Infiltration-Percolation Basins, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1977).
9. Larson, Alan L., Infiltration-Percolation Capacities and Groundwater Table Influence of a High-Rate Land Wastewater Disposal System, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1977).
10. Dickinson, John Peter, The Fate of Nitrogen in Wastewater Applied to Rapid Infiltration-Percolation Basins, Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1977).

11. Climatological Data - South Dakota, United States Department of Commerce National Oceanic and Atmospheric Administration, Environmental Data service, 81, Asheville, North Carolina, (July-November 1977).
12. Wisler, C. O., and Brater, E. F., Hydrology, 2nd. edition, John Wiley and Sons, Inc., New York, New York, p. 103-126, (1959).
13. McGauhey, P. H., and Krone, R. B., Soil Mantle as a Wastewater Treatment System, SERL Report No. 67-11, Sanitary Engineering Research Laboratory, University of California, Berkley, p. 34-68, (December 1967).
14. Recycling Municipal Sludges and Effluents on Land, Proceedings of the Joint Conference at Champaign, Illinois, Sponsored by the Environmental Protection Agency, the United States Department of Agriculture, and the National Association of State Universities and Land-Grant Colleges, p. 103-110, (July 9-13, 1973).
15. Seas, Richard G., Unpublished research data, Master of Science research, Civil Engineering Department, South Dakota State University, Brookings, South Dakota, (1977).
16. Drake, Tom, Unpublished research data, Master of Science research, Civil Engineering Department, South Dakota State University, Brookings, South Dakota, (1977).
17. Drainage of Agricultural Land, Published by Soil Conservation Service, United States Department of Agriculture, Water Information Center, Inc., Port Washington, New York, (1973).
18. Steel, Robert G. D., and Torrie, James H., Principles and Procedures of Statistics, McGraw-Hill Book Company, New York, N.Y., p. 74, (1960).

APPENDIX A
Infiltration Data

Parameters

Time Interval for Infiltration (hours), 1977

Change in Water Level (inches), 1977

Infiltration Rates (inches/hour), 1977

Infiltration Data During Percolation, inches/hour (1977)*

Date	Basin	Time Interval (hours)	Change in Water Level (inches)	Infiltration Rate (inches/hour)
August 31	South (S)	14.5	2.5	0.17
	Middle (M)	13.2	6.8	0.51
	North (N)	12.0	2.6	0.22
September 2	S	25.2	3.9	0.15
	M	---	---	---
	N	22.8	4.1	0.18
5	S	31.7	4.0	0.13
	M	---	---	---
	N	31.1	4.8	0.15
7	S	14.4	2.0	0.14
	M	5.0	4.0	0.80
	N	11.7	2.2	0.19
9	S	6.8	1.2	0.18
	M	5.6	4.2	0.76
	N	4.5	2.2	0.25
12	S	26.6	3.5	0.13
	M	5.3	4.8	0.89
	N	24.2	4.0	0.16
14	S	14.5	2.1	0.15
	M	5.0	4.2	0.85
	N	11.8	2.4	0.20
16	S	30.3	9.9	0.15
	M	---	---	---
	N	27.8	9.4	0.17
19	S	31.8	4.1	0.13
	M	5.3	4.6	0.87
	N	29.1	4.2	0.15
21	S	14.7	1.8	0.12
	M	9.0	7.9	0.88
	N	11.9	1.5	0.13
26	S	27.4	4.0	0.15
	M	7.4	5.2	0.71
	N	25.2	3.9	0.16

Infiltration Data During Percolation, (continued)

Date	Basin	Time Interval (hours)	Change in Water Level (inches)	Infiltration Rate (inches/hour)
September 28	S	10.4	1.8	0.17
	M	9.2	6.2	0.68
	N	7.9	1.2	0.16
30	S	49.5	6.0	0.12
	M	---	---	---
	N	49.5	6.8	0.14
October 3	S	6.8	0.5	0.07
	M	5.5	3.8	0.68
	N	4.7	0.4	0.08
5	S	14.8	2.6	0.18
	M	9.0	6.0	0.67
	N	12.2	2.5	0.20
7	S	58.7	6.2	0.11
	M	---	---	---
	N	56.2	7.1	0.13
10	S	33.9	4.8	0.14
	M	---	---	---
	N	31.3	4.9	0.16
12	S	14.4	2.6	0.18
	M	13.1	7.5	0.57
	N	11.9	2.0	0.17

*1 in./hr. = 25.4 mm/h

APPENDIX B

Climatic Data

Parameters

Precipitation Data, inches (1977), (11)

Temperature Data, °F and °C, Weekly Average (1977), (11)

Evaporation Data, inches per week (1977), (11)

Precipitation Data, inches (1977)*, (11)

Date															Total
July	6	11	14	17	20	24	28	30							1.71
	.11	.25	T	.07	.39	.77	.10	.02							
August	4	5	7	9	16	21	23	24	25	26	27	28	30	31	5.09
	.30	.49	.07	.20	.42	.01	.04	.20	.01	.42	1.05	.02	.06	1.80	
September	2	3	9	12	18	22	24	25	30						3.67
	.40	.08	.20	.03	.16	.93	1.26	.10	.51						
October	7	8	11	24	29	31									2.22
	.34	.97	.03	.03	T	.85									

*1 in. = 25.4 mm

Temperature and Evaporation Data (1977), (11)

Temperature	7-28	8-4	8-11	8-18	8-25	9-1	9-8	9-15	9-22	9-29	10-6	10-13
(Weekly Average) °F	69.2	68.1	64.3	60.5	58.6	64.1	63.4	58.6	57.1	56.1	45.1	39.6
°C	20.7	20.0	17.9	15.8	14.8	17.8	17.4	14.8	13.9	13.4	7.3	4.2
Evaporation												
(Weekly Total) in.	2.22	2.54	1.75	1.79	1.51	1.21	1.31	1.43	0.89	0.88	0.57	
mm	64.5	64.5	44.4	45.5	38.4	28.4	33.3	36.3	22.6	22.4	14.5	

APPENDIX C

Selected Ground Water Elevations

At The Pilot Unit

Water and Ground Water Levels, feet (1977)

Six Mile Creek

Well 81

Well 82

Well 83

Well 84

Water and Ground Water Levels (feet)

Location	7-22	7-25	7-27	7-29	8-1	8-8	8-10	8-12	8-15	8-17	8-19	8-22	8-14	8-26	8-29
Six Mile															
Creek	96.31	96.24	96.21	96.15	95.82	95.71	95.91	95.71	95.61	95.71	95.61	95.51	95.71	95.75	96.15
Well 81	96.03	95.98	95.92	95.84	95.65	95.71	95.73	95.65	95.39	95.50	95.47	95.32	95.31	95.41	97.29
Well 82	96.76	96.58	96.62	96.57	96.35	96.47	96.87	96.86	96.59	96.71	96.72	96.54	-----	96.64	96.88
Well 83	96.34	96.75	96.73	96.18	96.12	96.25	96.40	96.23	96.07	96.27	96.11	95.95	96.14	96.24	96.71
Well 84	96.10	96.06	95.80	95.69	95.44	95.60	-----	95.84	95.59	95.90	95.71	95.57	95.65	95.73	96.21

Location	8-31	9-2	9-5	9-7	9-9	9-12	9-14	9-16	9-19	9-21	9-23	9-26	9-28	9-30	10-3
Six Mile															
Creek	98.45	96.55	96.00	96.15	96.35	96.15	96.25	96.23	96.20	96.25	98.45	96.55	96.45	96.55	96.40
Well 81	-----	96.24	96.78	96.60	96.36	96.21	96.16	96.09	95.79	96.00	96.38	96.81	96.74	96.68	96.66
Well 82	97.30	97.63	97.70	97.61	97.52	97.38	97.32	97.26	97.16	-----	97.22	97.70	97.66	97.61	97.63
Well 83	96.94	97.40	96.89	96.85	96.71	96.36	96.45	96.40	96.36	96.96	96.96	97.06	96.87	96.88	96.87
Well 84	-----	97.58	96.98	96.72	96.54	96.30	96.32	96.27	96.14	-----	96.35	96.76	96.61	96.85	96.79

Location	10-5	10-7	10-10	10-12	10-16	10-17	10-18	10-19	10-20	10-21	10-24	10-27	10-29	10-31	11-2
Six Mile															
Creek	96.36	96.37	96.47	96.43	96.35	96.25	96.25	96.25	96.25	96.20	96.32	96.32	96.53	97.12	96.62
Well 81	96.58	96.57	97.33	97.16	96.85	96.65	96.55	96.51	96.45	96.36	96.26	96.28	96.24	97.08	96.93
Well 82	97.60	97.58	98.30	98.12	97.81	97.70	97.60	97.53	97.45	97.38	97.21	97.32	97.16	97.29	97.53
Well 83	96.88	96.80	97.14	97.03	96.80	96.66	96.60	96.58	96.54	96.48	96.44	96.47	96.51	96.86	96.89
Well 84	96.75	96.73	97.14	96.88	96.79	96.69	96.62	96.59	96.54	96.46	96.39	96.29	96.24	97.00	96.83

APPENDIX D. Analysis of Variance (18).

Source of Variation	Degrees of Freedom	Sum of Square	Mean Square	F Value
North Infiltration Rate X South Infiltration Rate	1	0.0064	0.0064	5.62*
Error	34	0.0387	0.0011	
Total	35	0.0451		
North Infiltration Rate X Middle Infiltration Rate	1	2.339	2.339	338.15**
Error	28	0.1937	0.0069	
Total	29	2.533		

*Indicates significance at the 0.05 level.

**Indicates significance at the 0.01 level.